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R.P. Ritchie, B.A.

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INVESTIGATIONS ON THE USE OF A SEMICONDUCTOR LASER SOURCE FOR TRANSMISSION OF BASEBAND VIDEO OVER OPTICAL FIBRES

R.P. Ritchie, B.A.

Summary

Optical fibres show great promise for high quality communications links because they do not require equalization for path length and so can be set up very quickly.

Simple l.e.d. sources are not sufficiently linear for broadcast quality transmission of baseband video. The semiconductor laser sources investigated here have a much more linear region to their output characteristic. However, a major signal impairment is present in the form of modal distortion. This is introduced at fibre connectors, and is a property of the coherence of the laser source.

Although a laser of reduced coherence was used in our experiments, modal distortion reduced the signal quality below the standards required for broadcast. Further reductions in modal distortion will be necessary before a baseband video link of broadcast quality can be realized.

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1. Operation of laser diodes

1.1. Introduction

Semiconductor light sources for fibre optic communication fall into two classes: light emitting diodes (l.e.d.s) and laser diodes. The laser diode is an l.e.d. with the two ends of its active region cleaved into mirrors to form the cavity of the laser. At low currents it behaves as an l.e.d. with an approximately linear increase in light power output with current. Above a threshold level the optical gain within the cavity exceeds absorption and the light output increases much more rapidly with current. (A typical curve is shown in Fig. 1.)

Lasers can couple more power into a fibre than l.e.d.s and, above threshold, their output light-current characteristic can be more linear. They also have a much higher signal bandwidth (in excess of 1 GHz), and a narrow spectral width (< 0.1%) which results in low distortion due to material dispersion in the fibre. The laser output is, however, coherent, and this can lead to additional noise and distortion due to interference between light travelling in different fibre modes. Also the level of threshold current at which laser action begins is highly dependent upon temperature, as is the slope of the light-current characteristic above threshold. Unless the chip temperature can be very accurately controlled, the output must be stabilized using a feedback loop from the light output of the laser.

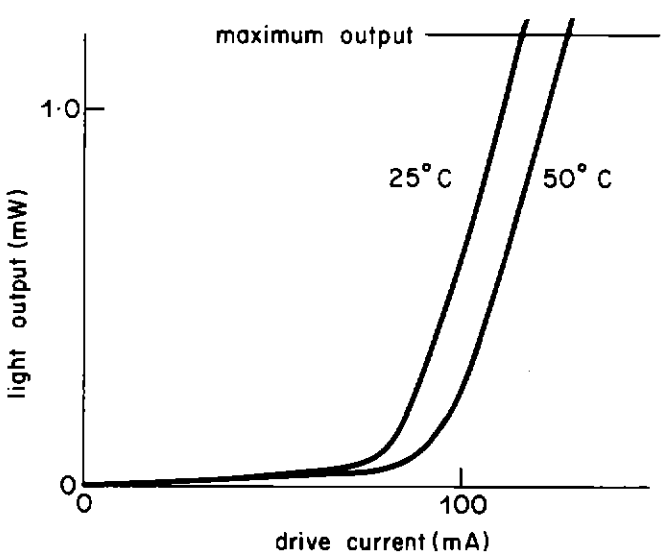


Fig. 1 - Typical power output as a function of drive current

1.2. Derivation of feedback signal

The optical output of the laser must be tapped to provide a reference for a feedback loop to counteract variations in gain and threshold with temperature. To detect the output from the front face, an optical tap would be required in the fibre output. A simpler alternative is to monitor the output from the rear face of the laser. In the short term this will be directly related to the front face output, but as the laser ages small variations in the relationship may occur, particularly in the case of facet damage. Rear face monitoring was chosen in this case because it offers advantages in reduced complexity and cost, and increased mechanical stability.

1.3. Source coherence – modal noise and distortion

The laser is a coherent source of light, and so speckle patterns will occur at the end of a multimode fibre, caused by interference between light propagating down the fibre in different modes. Manipulation of the fibre at any point will change the pattern. Unless all lobes of the pattern are passed on to the detector, variations will occur in the output level, an effect that has been called modal noise.[1] In a typical 50 μm core fibre system, light from a laser will propagate in approximately 1,000 modes.[2] Unless measures are taken to reduce the coherence of the laser, the contrast of the speckle pattern will only be substantially reduced after several kilometres of fibre.[3]

There is an associated problem known as modal distortion. The principle is similar, but now the speckle pattern changes because of variations in the frequency of the laser light. This frequency depends upon the instantaneous temperature of the laser cavity, which in turn depends upon the signal current. The speckle pattern thus varies with input current, so that the coupling efficiency of any lossy joint will vary with the instantaneous signal level, resulting in distortion. It is difficult to predict the level of modal noise and distortion accurately, since so many factors are involved. It can be minimized

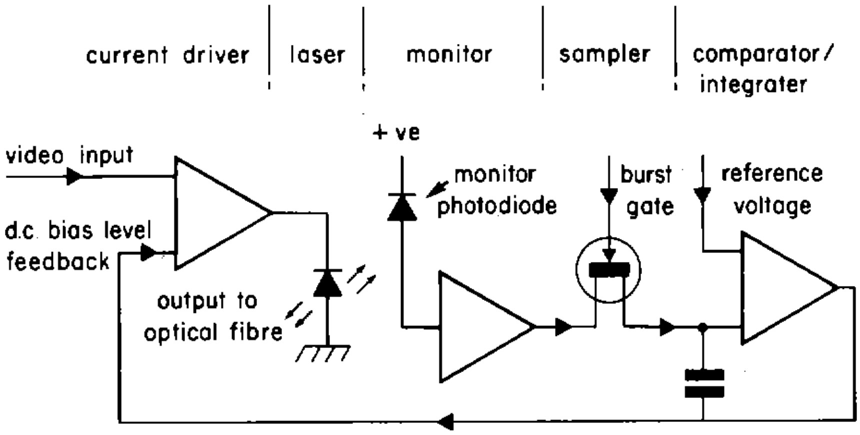


Fig. 2 - Schematic diagram of stabilizing feed-back loop using rear-face output of laser

by using efficient connectors and by ensuring that the laser line width is as broad as possible, thus reducing its coherence.

2. Baseband video laser link

An optical transmitter for analogue baseband television signals was constructed with which to investigate the performance of the laser diode source. A narrow stripe laser was chosen, operating at 850 nm wavelength. This device has an inherently broad spectral width, which reduces the coherence of the output.[4] Above threshold its output light-current characteristic also shows negligible variation of slope with temperature. Thus only a single d.c. feedback loop need be used, to counteract variations in threshold. A block diagram of the circuit is shown in Fig. 2. Since baseband video signals were transmitted, the optical output could be controlled by sampling the laser output once per video line in the back porch, and stabilizing this d.c. level, in the manner of a black-level clamp.

In order to simplify the a.g.c. design in the receiver, negative modulation was used. The a.g.c. detects and adjusts the peak level of the received signal. Since the system is d.c. coupled throughout, both the d.c. level and the amplitude of the received video signal are then determined. Positive modulation may also be used, but more complex circuits would be required, not only in the receiver, but also in the transmitter to protect the laser from overload.

The fibre used had a 50 μm graded-index core and a numerical aperture of 0.2. Attenuation was quoted as 4.2 dB/km and modal dispersion as 1 ns/km. For the spectrally broadened laser used, material dispersion will be less than 1 ns/km. Thus for a baseband link the maximum distance will be limited by signal-to-noise considerations rather than by dispersion.

3. Performance of baseband link

The various parameters of the baseband link using the laser driver of Fig. 2 were measured. Without connectors in the fibre the signal was of high quality. When fibre connectors were introduced, modal distortion was seen, appearing as low-frequency luminance non-linearity.

3.1. Signal-to-noise

The signal-to-noise ratio of received signals was measured at 59 dB unweighted (66 dB CCIR colour weighted). This may be compared with an expected signal-to-noise figure, calculated from receiver shot and thermal noise, of 73 dB for the power level received on test. The difference is attributed to source excess noise. The laser specification quotes an excess noise figure of 56 ± 3 dB.[4] This excess noise, in the form of random variations in laser light output, can be caused by localized changes in carrier density within the cavity of the laser, and is a property of the laser diode. The signal-to-noise performance of the link will be dominated by source excess noise for optical received powers in excess of 10 μW. Thus the signal-to-noise level will only degrade below source noise level if optical losses exceed 20 dB.

3.2. Differential phase and gain, and modal distortion

Measurements were made of the distortion introduced by the link using various standard test signals, and the major impairment found was due to modal distortion.

With no connectors in the fibre, differential phase of ±½° was achieved, and differential gain was less than 2%. However, when a connector

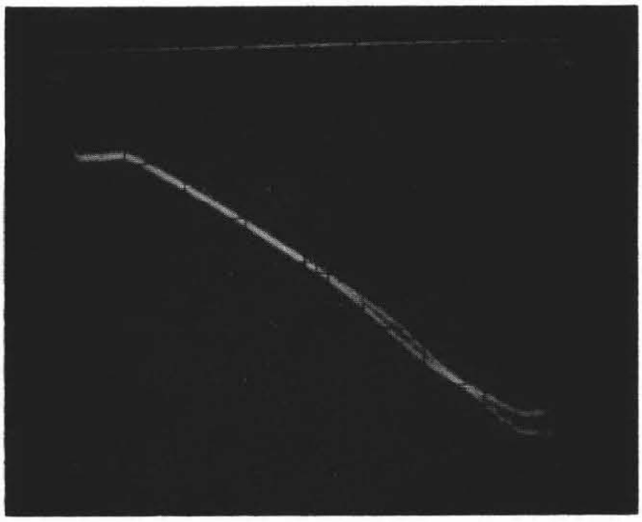


Fig. 3 - Typical change in distortion due to modal noise as the fibre is moved prior to a connector
NOTE: Two superimposed photographs show change in response for a sawtooth waveform

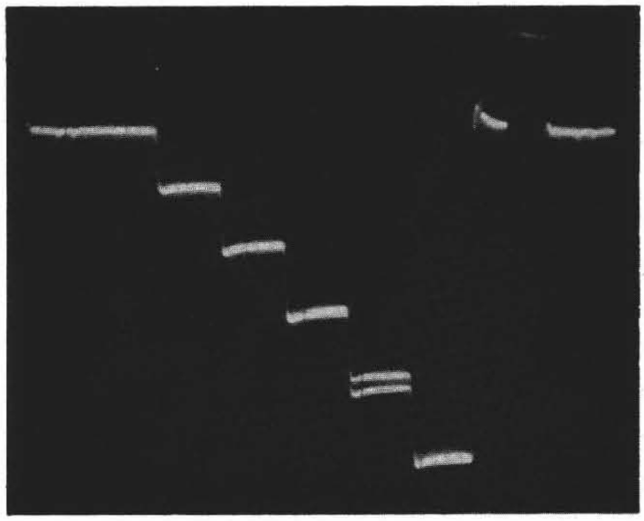
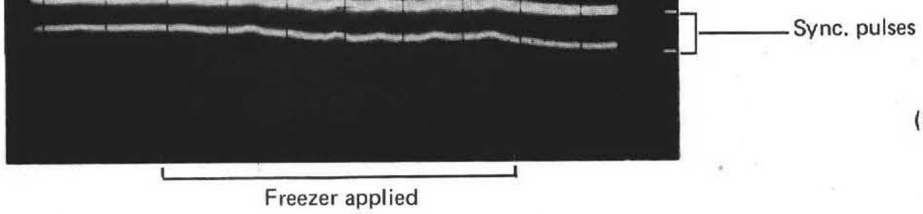


Fig. 4 - Distortion with lateral displacement of one turn on drum of fibre by 2 mm
NOTE: Two superimposed photographs of a staircase waveform

was introduced, modal distortion was observed. Differential gain at subcarrier frequency was little affected, but kinks were seen in a linear sawtooth waveform. These kinks varied when the fibre was moved at any point prior to the connection (Fig. 3). By varying the d.c. bias, or by heating or cooling the heatsink, the kinks could be made to run up and down the slope of the sawtooth. When linearity was measured for a fibre with one connection after 100m, the worst-case differences in step height of a staircase waveform were greater than 10% (see Fig. 4).

The laser is often packaged with a short 'pigtail' of fibre attached to it, which is connected to longer fibre lengths for transmission. When a pigtail of 30 μm core fibre was used, followed by a single 300m length of 50 μm core fibre, step height variations of up to 4% were seen, in spite of the high coupling efficiency expected from a small to a large diameter core. With this short initial length of 30 μm core fibre, it is possible that light was propagating along the cladding outside the narrow fibre core, resulting in speckle patterns in the cladding at the pigtail end. Some of this light would couple with the 50 μm fibre core at the connector and cause modal distortion.

The variation of modal distortion with temperature is illustrated in Fig. 5. Staircase waveform was transmitted, as in Fig. 4, and the output displayed on an oscilloscope. The figure shows



(Horizontal scale 1s/division)

Fig. 5 - Modal noise on staircase waveform, with 'freezer' applied to heatsink
NOTE: A slow horizontal scan is used with 1 second per division

the output over ten seconds, with freezer spray applied to the laser heatsink over the central six seconds. No modal distortion is seen on the lower steps, which were biased below the lasing threshold. Variations in level are seen above threshold, moving with time from the lower to the upper steps as the laser cools and its wavelength changes. Since the laser was biased below threshold, the clamp was inoperative, and the staircase steps are not of uniform height.

An attempt was made to reduce the coherence of the laser by artificially broadening the linewidth. A high frequency dither signal, up to 100 MHz, was added to the input signal, in order to vary the chip temperature with a period short compared to the signal frequencies. This would modulate the laser's operating wavelength, and have the effect on band limited signals of further broadening the source linewidth. It was found that this changed the d.c. level at which kinks occurred, but no overall improvement was found. The thermal coupling between chip and heatsink appeared to be high enough to smooth any high frequency temperature variations.

3.3. Intermodulation products

The linearity of the system was checked using a 6 MHz sound carrier which was added to the input video signal. The levels of the first order intermodulation products between this and the colour subcarrier were measured both at the input to the laser, and at the system output. At both points these were more than 55 dB below the level of peak syncs, and hence intermodulation products produced in the laser itself were well below −55 dB. For good quality links the specified maximum intermodulation level is −52 dB on peak syncs.

3.4. Other distortion mechanisms

A further form of distortion was observed on large signal transients for certain coupling conditions between the laser and fibre. This took the form of a sag on d.c. levels over a period of approximately one microsecond after a transient. It was particularly visible on the bottom of syncs and on the bar of pulse and bar test signal. The distortion was initially seen when using a laser which was supplied with a short fibre pigtail already connected. Once the coupling between the pigtail and the laser had been disturbed it was very difficult to reproduce the effect. The most likely explanation is that light reflected back into the laser cavity from the fibre end was affecting the gain of the laser. When present, this distortion did not appear to be affected by changes in the temperature or the drive conditions of the laser, but it could be removed by adjusting the fibre end.

4. Discussion

The transmitter described above provided satisfactory signals over single fibre lengths of up to 500m, the longest single fibre length available. Impairments were seen caused by back reflections at the laser-fibre interface but these were removed by realigning the fibre. When more than one length of fibre was used, the effect of reflections from the fibre connector could also be detected: as the joint was manipulated variations of up to 2% were seen in the level of the signal received at the laser back face monitor. No additional distortion could be detected in this case, but in some systems a full-bandwidth feedback loop may be required to correct for non-linearity due to back reflections.

The most important impairment in the system was caused by modal distortion whenever fibre connectors were used. This degraded the signals to an unacceptable extent, although subjectively the distortion introduced was not annoying. Since modal distortion is generated at fibre connectors in the transmission path, it cannot be removed by feedback or precorrection; instead the coherence of the laser must be reduced. The narrow stripe laser was designed to operate c.w. in more than one longitudinal mode. It radiates at a series of closely spaced frequencies, reducing the coherence by effectively broadening the linewidth to 2 nm, compared to 0.1 nm for a typical single mode c.w. laser. Thus the level of modal noise and distortion encountered was significantly below that expected from a normal c.w. laser. Unfortunately the lifetime of these lasers did not live up to expectations and they are no longer available. Other methods of reducing coherence will be necessary in future systems.

Dither signals can be used to broaden the linewidth artificially by thermally sweeping the laser output wavelength. Considerable reduction in modal distortion has been reported using this technique[1,5] on single-mode lasers, which suffer from severe modal noise and distortion. However, it is not clear whether the level of distortion was reduced to the levels achieved by the narrow stripe laser. In the short range of tests conducted with dither on the narrow stripe laser, no further reduction in the level of modal noise was found.

It is possible to broaden the linewidth of

some lasers artificially by pulsing them at high frequency from below threshold. When driven in this way the output does not settle down into a single lasing mode, so the spectrum is much broader. This has been successfully used for high bit rate digital systems.[1] Some reduction in modal noise has also been reported for an analogue system, upon which a pulsed waveform was superimposed. A reduction in differential gain from 20% to 5% has been reported using this technique.[6] However, to keep the spectrum broad, the pulse width must be limited to approximately 5 ns. When biased below threshold there is a delay of up to 0.5 ns before the laser turns on.[7] There is therefore a residual non-linearity which could be in excess of 5%. A full-bandwidth feedback loop would be necessary to correct distortion introduced by this ratio of turn-on-delay to pulse-width, if the linearity of the system is to be sufficient to transmit baseband signals.

5. Conclusions

Provided that modal noise and distortion can be reduced, laser diodes can be used as sources for analogue transmission of baseband video signals. No lasers are currently available, however, with sufficiently broad output spectrum to overcome modal noise and distortion. Further work is needed to check how effective spectral broadening techniques can be for reducing modal distortion in nominally single mode lasers.

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